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Applications of Radio Altimetry to Balloons

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8. Applications of Radio Altimetry to Balloons

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Abstract

A newly developed radio altimeter enables geometric altitude measurements of meteorological balloons up to altitudes of 35 km over water, and 12 km over land. The one-watt peak power pulsed-radar is simple and light enough to be carried by regular sounding balloons with radiosonde. Flight tests conducted on standard radiosonde flights over water indicate that the random error averaged over one second is less than 0.1 percent. Power consumption is one-watt average; weight excluding batteries is ten oz.

An independent, accurate altitude measurement proves very useful in a variety of balloon experiments. As an accurate ranging device, it is expected that this altimeter can fill ready applications in GARP.* Two flight tests have already been performed on-board GHOST balloons. Current work is progressing in multiplexing additional channels of slowly-varying information, such as derived from barometric sensors, on the carrier frequency of the altimeter. This will provide the balloon experimenter with a very accurate and reliable radiosonde. Resulting experiments are limited only by the imagination of the experimenter.

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* Global Atmospheric Research Program

8.1 INTRODUCTION

A direct measurement of geometric height is not often included in balloon instrumentation requirements. Normally temperature, pressure and humidity are sufficient to obtain a vertical profile, particularly when samples are taken frequently and the altitude is low. With increasing use of superpressure balloons and an increasing emphasis on accuracy at higher altitudes, however, the possibilities of absolute height measurements become quite attractive. A radio altimeter is described here which was developed specifically for making such measurements from balloons.

Various types of radio or, more specifically, radar, altimeters have been designed and built for aircraft, rocket, and satellite applications. In contrast, the use of such a device on a balloon poses some very different and often very stringent requirements. The radar must be self-contained and accurate with no special operator requirements. It should be able to operate over wide temperature ranges (for example, -55°C to +55°C) without sacrificing accuracy. It should operate reliably up to 30 km or more and yet consume very meager amounts of power. And above all, it should be cheap and not weigh more than a few hundred grams!

Obviously some compromises must be made. However, we have made an attempt to meet as many of the demands as possible in a prototype design. To keep the design simple, a pulse-type radar is used which seeks and determines its own repetition rate, eliminating elaborate timing circuits. A single transistor is used as a superregenerative receiver and transmitter. The basic design strategy is to make this circuit operate at a repetition rate determined by the altitude of the balloon.

8.2 PRINCIPLE OF OPERATION

The radio altimeter described here is a pulse-radar system in which the elapsed time period between transmitted pulses is a measure of altitude. A single rf superregenerative stage serves as both the transmitter and the receiver. This stage is an oscillatory circuit held from oscillating by a negative quench voltage. When a positive quench pulse is applied, oscillations are allowed to grow. A pulse of radio frequency (rf) energy results whose envelope area depends on the rf input signal present when the quench pulse is applied. The frequency of oscillation is carefully controlled in these units by coupling to strip lines etched on a teflon circuit board.

As the pulse period approaches the delay time of a previously transmitted pulse returning from the ground, the envelope of the superregenerative circuit output reaches a peak. If the rf superregenerative stage is gated-on a little too early or a little too late, the envelope area decreases, as illustrated in Figure 8.1. The correct operating repetition period T is:

$$T = \frac{2h}{c}$$

where h is the altitude and c is the velocity of light.

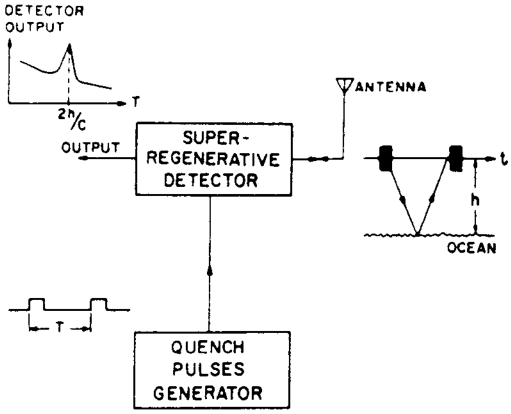

Figure 8.1. The Output of the Superregenerative Detector Peaks When the Quench Pulse Period Equals the Delay of the Return

The overall operation of the superregenerative rf stage suggests that an error signal could be derived to drive the repetition rate to the correct value. The remainder of the altimeter circuitry is needed to generate this error signal, both in magnitude and sense, to filter it, and to adjust the repetition rate accordingly to keep the error small. A block diagram of the complete radio altimeter is shown in Figure 8.2. The voltage-controlled oscillator (VCO) determines the repetition rate of the quench pulses. A sinusoidal voltage at a preset frequency, f_p, is added to the derived error signal to vary the repetition rate about the correct value. Variations at this frequency in the superregenerative detector output are amplified and then multiplied by the sinusoidal voltage, to derive a slowly-varying error voltage for controlling the repetition rate. An integrator is used to average the error voltage. Typical values are 200 Hz for f_p and a one-second time constant in the integrator.

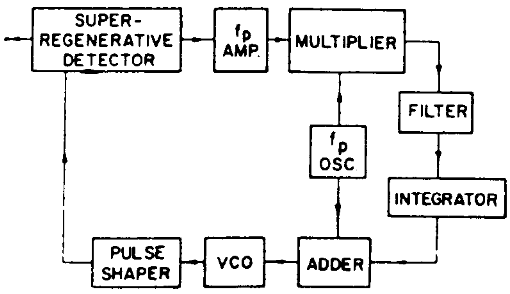

Figure 8.2. Block Diagram of the Radio Altimeter.

For short transmitted pulses, the shape of the returned pulse is an integrated version of the transmitted pulse in cases of scattered reflections, and an attenuated replica of the transmitted pulse in cases of specular reflection, as shown in Figure 8.3 (Levanon, 1970). In both cases, there is a relatively well-defined break point in the returned pulse at the point corresponding to the trailing edge of the

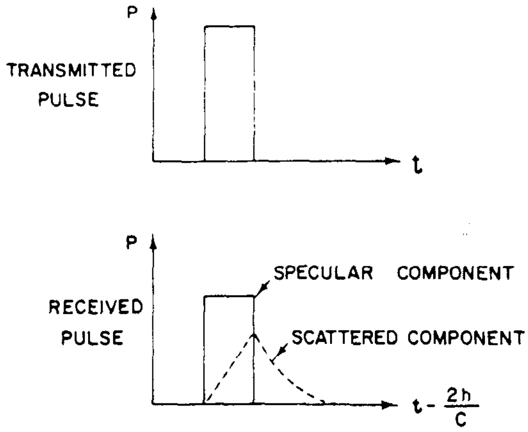

Figure 8.3. Simplified Return Pulse Envelopes

transmitted pulse. Taking advantage of this fact, the altimeter is made to scan from longer to shorter repetition periods and locks on the trailing edge.

The closed-loop response shows a close resemblance to the familiar phase-lock loop (Gardner, 1966). The main parameter of such a loop is its bandwidth which is, approximately, the reciprocal of the signal averaging time. Lowering the loop bandwidth reduces the effects of noise and fluctuations in the returned pulses. On the other hand, the altimeter is required to follow altitude changes and must also be able to acquire lock within a reasonable amount of time. For ascending radiosonde balloon flights, a bandwidth of 1 Hz appears to be a reasonable compromise, while for superpressure balloons the bandwidth can be less.

8.3 RANGE AMBIGUITIES

The idea of transmitting a pulse as soon as a previous one is received is certainly an efficient means of operation for a radar altimeter and has been suggested for aircraft use (Jacob, 1967). A drawback of the method, however, is the presence of range ambiguities which can result. Under certain conditions this is not too serious for balloon flights as long as some other means for coarse altitude readings is available.

The range ambiguity problem arises because there is no reason why the altimeter cannot transmit a second pulse before the previous one is received. This subharmonic mode of operation (see Figure 8.4) can occur at any altitude above twice the minimum altitude of operation if locking is lost. In other words, the range ambiguity is equal to the minimum altitude of operation.

The exact relation between the geometric altitude, h, and the pulse repetition period, T, is:

$$h = \frac{c}{2}(nT - \tau)$$

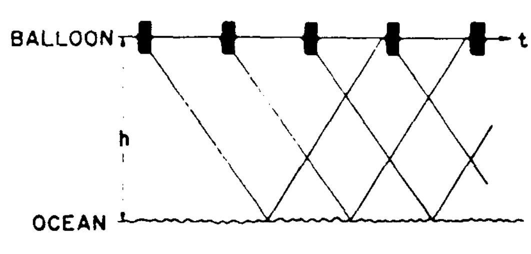

Figure 8.4. Subharmonic Altimeter Operation

where n is the subharmonic mode number and τ is the (fixed) delay between the beginning of the quench pulse and the end of the transmitted pulse. The parameter can be measured and controlled accurately in the altimeter design. The VCO range can be preset arbitrarily for the minimum and maximum allowable repetition rate. Assuming a two-to-one VCO range and a minimum altitude of 2 km, the pattern of switching modes as the balloon ascends, for no loss of locking except at end of range, is shown in Figure 8.5.

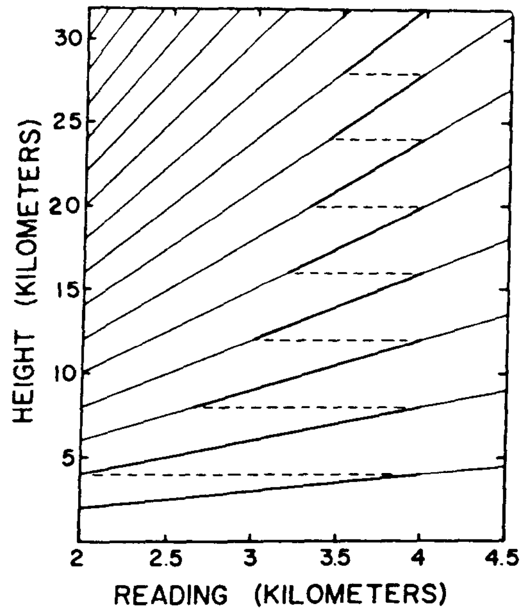

Figure 8.5. Range Ambiguity Pattern

Subharmonic operation is desirable to a certain extent, particularly at high altitudes, because the quench pulse frequency remains high, yielding more pulses per unit time. Therefore there is a greater average transmitted power and better signal-to-noise ratio. Range ambiguities are equal to the minimum attitude and can be resolved by pressure readings or by extrapolation of the balloon ascent data.

Subharmonic operation is recommended even if the range of operation is limited, as in the case of the superpressure balloons. It is possible not only to assure that only one mode will cover a given limited range, but that the subharmonic mode numbers can be chosen to give several different ranges with no changes in circuitry. As an example, suppose that an altimeter is designed with a maximum repetition period range of 25μ sec. to 30μ sec. This altimeter will measure altitudes over about a 3 km range centered at 200 mb on the third subharmonic and centered at 100 mb on the fourth subharmonic with no changes in circuitry.

The maximum altitude of operation is influenced by transmitter power, antenna gain, choice of operating frequency, terrain, etc. The upper limit for altimeters currently being used is 35 to 40 km over water and 12 to 15 km over land using 5-element yagi antennas at 403 MHz. Larger antennas can be used but not without an accompanying increase in bulk and weight. An altimeter operating at 1680 MHz requires 12 db more gain than one operating at 403 MHz to give the same performance. Most of this can be made up in antenna gain.

8.4 OUTPUT DATA

The best means of extracting the altitude data is counting the pulse repetition rate. In short range balloon flights, such as radiosonde flights, this is relatively easy since the ground station is within receiving range of the altimeter radar pulses. A block diagram of such a ground station is shown in Figure 8.6. This scheme is quite inefficient, however, because it uses 100 kHz of bandwidth to receive a signal of 1 Hz bandwidth.

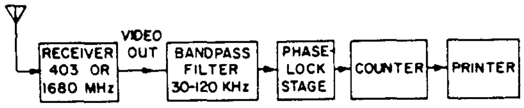

Figure 8.6. Block Diagram of Ground Station

In longer balloon flights, such as GHOST flights, it is more efficient to make a bandwidth reduction on-board the balloon package before transmission. One method of doing this is to multiply the VCO signal with a fixed frequency from a crystal oscillator. The difference frequency is then counted down (by a factor of 1024 in present GHOST flights) before the data is telemetered.

An alternative is to sample the voltage at the input to the VCO and use the analog information for the telemetry signal. However, this requires a very linear, temperature-stable VCO characteristic and some degradation in performance can be expected. An altimeter for the IRLS* flights is being tested using this approach.

8.5 TEST RESULTS

As of 1 May 1970, nine flight tests and several ground tests of the altimeter have been made and several more are pending. Four aircraft flights were made to test prototype models and to gather information on the shape of the return pulse. Three regular radiosonde balloon flights were made, one over local terrain and two over Lake Michigan (Levanon and Suomi). The latter two of these flights demonstrated that an early version of the altimeter could measure altitudes accurately up to 18 km over water. Two GHOST flights have been made from Christchurch, New Zealand and a third is pending.

The first GHOST balloon was launched to 100 mb (15.8 km). The electronics payload included the regular GHOST package plus the radar altimeter and solar panels to supply power to the altimeter. Interference between the telemetry system and the altimeter prevented proper operation of the altimeter. A second GHOST balloon was launched to 200 mb (12.2 km) on 3 October 1969. From the

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* Interrogration, Recording, Location Subsystem.

data received, the altimeter provided altitude readings for about seven hours. Data transmission ended as the sun dropped below 20 degrees incidence, reducing the power available from the solar cells below the operational level. Unfortunately, the balloon went down during the night.

All the above flight tests were made using altimeters with vacuum tube rf stages. To conserve power, an effort was started in January to redesign the altimeter using all solid-state components. The resulting new electronics for the 403 MHz altimeter is shown in Figure 8.7. A photograph of the 403 MHz altimeter with its antenna is shown in Figure 8.8.

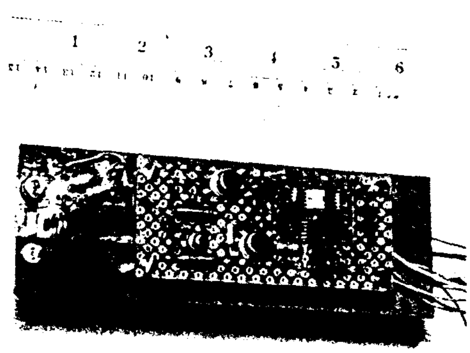

Figure 8.7. Electronics Package of the Radio Altimeter

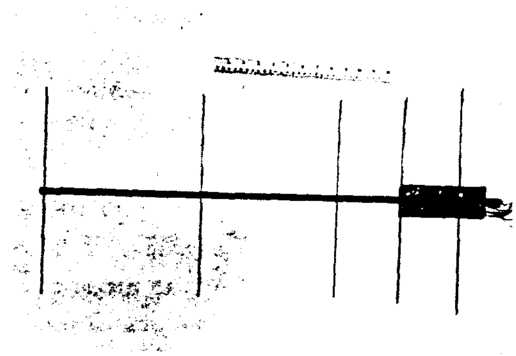

Figure 8.8 Radio Altimeter Being Used in GHOST Balloon Flights

Recent tests have shown that the new altimeter model has enough sensitivity to lock on specular components in ground clutter, for example, metal roofs of buildings, etc., beyond the minimum range of the unit. A very convenient and inexpensive test is to point the altimeter at the horizon from the top of a tall building.

Altitude measurement error in a laboratory calibration setup is less than ± 3 meters over a one-second integration time. Minimum signal to maintain lock is 3 μv at the antenna terminals. Weight distribution of present models is:

Electronics	4 oz
Antenna	3 oz
Packaging and cabling	3 oz
	10 oz

Power required is one watt at ± 12 V. Light-weight solar panels are being used for the superpressure balloon flights.

A prototype of a solid-state altimeter operating at 1680 MHz has been built and tested. Transistors are still very expensive for this operating range, and temperature stability is more of a problem than at 403 MHz. Work in this area is continuing.

8.6 EXTENSIONS

The foregoing has described what has been done with the radio altimeter concept. Tests indicate that the altimeter is a very useful and practical meteorological tool. Here we discuss several extensions of these ideas for continued study and development.

The altimeter operation is not affected by changes in the carrier frequency. We have found that the frequency can be tuned using a diode, and thus information can be multiplexed on the center frequency. It is quite conceivable for example, that temperature, pressure, and humidity information can be multiplexed on the center frequency of the altimeter.

The altimeter is quite insensitive to other pulsed signals and moderately insensitive to other CW signals. It is very sensitive to other signals near its center frequency which have a tone modulation near the 200 Hz tone used for the error signal. This suggests the use of tone-modulated signals to capture or perturb the altimeter operation, allowing opportunities for interrogation or ranging from a controlled transmitter. Measurements of winds are a distinct possibility in this way.

Perhaps one of the greatest disadvantages in finding widespread meteorological applications for these altimeters is cost. Parts costs alone total $200.00 for present units. At least half of this is directly attributable to the use of military grade components, particularly the integrated circuits, to meet the rigid temperature specification.

We anticipate that many cost-saving cuts can be made in the design without sacrificing very much in performance. Possibilities in integrated circuit design, particularly on mass produced levels, could also make significant reductions in cost. In short, even though the present altimeter is several orders of magnitude below the cost of other airborne radars, the possibility of a truly expendable altimeter whets the appetite of the experimenter!

Acknowledgments

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